

DTIC FILE COPY

USAFSAM-TR-88-7

20030130068

AD-A193 854

**THERMAL STRESS IMPOSED BY PROTOTYPE
BILAYER AND CURRENT GROUND CREW
CHEMICAL DEFENSE ENSEMBLES**

A Limited Laboratory Comparison

Larry P. Krock, Ph.D.
Rufino Navaleta, Technical Sergeant, USAF
Loren G. Myhre, Ph.D.

July 1988

DTIC
ELECTE
OCT 25 1988
S D
CH

Interim Report for Period June 1986 - January 1987

Approved for public release; distribution is unlimited.

USAF SCHOOL OF AEROSPACE MEDICINE
Human Systems Division (AFSC)
Brooks Air Force Base, TX 78235-5301



RR 1034 704

NOTICES

This final report was submitted by personnel of the Chemical Defense Branch, Crew Technology Division, USAF School of Aerospace Medicine, Human Systems Division, AFSC, Brooks Air Force Base, Texas, under job order 2729-04-04.

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility or any obligation whatsoever. The fact that the Government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication, or otherwise in any manner construed, as licensing the holder or any other person or corporation; or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

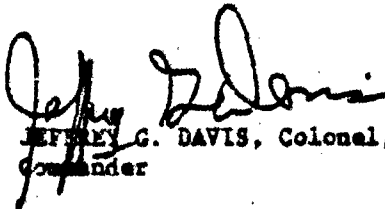
The voluntary fully informed consent of the subjects used in this research was obtained in accordance with AFR 169-3.

The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.


LARRY P. KROCK, Ph.D.
Project Scientist


F. WESLEY BAUMGARDNER, Ph.D.
Supervisor


JEFFREY G. DAVIS, Colonel, USAF, MC
Commander

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
1a. REPORT SECURITY CLASSIFICATION Unclassified			1b. RESTRICTIVE MARKINGS		
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.		
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE			5. MONITORING ORGANIZATION REPORT NUMBER(S)		
4. PERFORMING ORGANIZATION REPORT NUMBER(S) USAFSAM-TR-88-7			7a. NAME OF MONITORING ORGANIZATION		
6a. NAME OF PERFORMING ORGANIZATION USAF School of Aerospace Medicine		6b. OFFICE SYMBOL (If applicable) USAFSAM/VNC		7b. ADDRESS (City, State, and ZIP Code)	
6c. ADDRESS (City, State, and ZIP Code) Human Systems Division (AFSC) Brooks AFB, TX 78235-5301			9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER		
8a. NAME OF FUNDING/SPONSORING ORGANIZATION USAF School of Aerospace Medicine		8b. OFFICE SYMBOL (If applicable) USAFSAM/VNC		10. SOURCE OF FUNDING NUMBERS	
8c. ADDRESS (City, State, and ZIP Code) Human Systems Division (AFSC) Brooks AFB, TX 78235-5301		PROGRAM ELEMENT NO. 62202F		PROJECT NO. 2729	TASK NO. 04
				WORK UNIT ACCESSION NO. 04	
11. TITLE (Include Security Classification) Thermal Stress Imposed By Prototype Bilayer and Current Ground Crew Chemical Defense Ensembles: A Limited Laboratory Comparison					
12. PERSONAL AUTHOR(S) Krock, Larry P.; Navalta, Rufino; and Myhre, L. G.					
13a. TYPE OF REPORT Interim		13b. TIME COVERED FROM 86/06/30 TO 87/01/01		14. DATE OF REPORT (Year, Month, Day) 1988, July	
15. PAGE COUNT 21					
16. SUPPLEMENTARY NOTATION					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	Chemical Defense; Thermal Stress; Ground Crew Chemical Defense Ensemble; Open Bilayer, Chemical Defense Ensemble.		
06	07				
15	06	03			
19. ABSTRACT (Continue on reverse if necessary and identify by block number)					
<p>An open bilayer ground crew chemical defense ensemble (CDE) has been proposed to reduce the thermal burden during vapor-only exposure periods. This study compared the thermal stress profile of the proposed ensemble to that produced by the currently employed closed CDE. Four subjects, alternating ensembles on separate days, walked on a treadmill in an environmental chamber at 5.3 km/h² (3.3 mph) and 2% grade (an energy expenditure of 350 kcal/h²) for alternating work/rest cycles of 30 and 10 min, respectively. Chamber conditions were: T_{db} = 27 °C (80.6 °F), T_{wb} = 19 °C (66.2 °F) and airspeed approximately 2 m s⁻¹. Work segment analysis indicated a significant (p<.05) stress-dependent difference between the 2 ensembles for parameters of rectal temperature, skin temperature, and heart rate. The rest intervals were insufficient to achieve significant recovery. Mean total sweat production was lower (1.38 vs. 2.50 Liters) and percent sweat evaporation greater (65.7% vs. 30.0%) in the prototype ensemble than in the CDE. The prototype ensemble provided greater heat dissipation and allowed more efficient sweat evaporation--which had the double benefit of reducing heat storage and limiting dehydration.</p>					
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT <input type="checkbox"/> DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION Unclassified		
22a. NAME OF RESPONSIBLE INDIVIDUAL Larry P. Krock, Ph.D.			22b. TELEPHONE (Include Area Code) (512) 536-3814		22c. OFFICE SYMBOL USAFSAM/VNC

DD Form 1473, JUN 86

Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

CONTENTS

	<u>Page</u>
INTRODUCTION.	1
EQUIPMENT AND PROCEDURES.	2
Equipment	2
Current Chemical Defense Ensemble.	2
Bilayer Chemical Defense Ensemble.	2
Procedures.	5
Experimental Protocol.	5
Data Analysis.	6
RESULTS	7
Work Cycles	7
Core (Rectal) Temperatures	7
Skin Temperatures.	7
Heart Rates.	10
Rest Cycles	10
Post-work Recovery.	10
Thermal Sweating.	13
DISCUSSION.	13
CONCLUSIONS	14
REFERENCES.	15

List of Figures

<u>Fig.</u> <u>No.</u>		
1.	Current Ground Crew Chemical Defense Ensemble.	3
2.	Prototype Bilayer Ground Crew Chemical Defense Ensemble.	4
3.	Outline of Experimental Protocol	6
4.	Physiological Profile for One Subject.	8
5.	Mean Temperatures and Heart Rates During Work Periods.	9
6.	Mean Temperatures and Heart Rates During Rest Cycles	11

<u>Fig.</u> <u>No.</u>		<u>Page</u>
7.	Mean Temperatures and Heart Rates During Recovery Periods	12
8.	Mean Sweat Production and Percentage Evaporation	14

List of Tables

<u>Table</u> <u>No.</u>		
1.	Physical Characteristics of Subjects	5
2.	Mean Sweat and Evaporation Values.	13



Accession For	
Microfilm	<input checked="" type="checkbox"/>
Microfiche	<input type="checkbox"/>
Other	<input type="checkbox"/>
Distribution/	
Availability Codes	
Avail and/or	Special
Int	
A-1	

THERMAL STRESS IMPOSED BY PROTOTYPE BILAYER AND CURRENT GROUND CREW CHEMICAL DEFENSE ENSEMBLES

A Limited Laboratory Comparison

INTRODUCTION

The problems involved with task performance while wearing the chemical defense ensemble (CDE) have received increased attention during recent base readiness exercises. Physiological monitoring of volunteer subjects during these exercises has raised concerns about the physical ability of ground crews to perform some operational tasks, especially in warm environments. The principal physiologic concern is the excessive thermal stress that is incurred by individuals wearing the present CDE.

Ground crew personnel performing rapid runway repair--perhaps the most physically demanding of U.S. Air Force (USAF) operational tasks--while wearing the CDE, demonstrated very rapid increases in core temperature under moderate environmental conditions. This rapid storage of body heat would have limited their ability to complete more than 1 h of work had they not succumbed to fatigue before becoming a thermal casualty (1).

Yousef et al. (5) found similar heat stress problems in individuals performing integrated combat turnarounds while wearing the CDE under summer desert conditions. The investigators also concluded at temperatures above 30 °C (86 °F) the tolerance time for a loader is 40-50% less than that of the crew chief and that the loader would be limited to only 2 turnaround exercises. If the ordnance loader was not replaced at that time, the entire crew would become nonoperational. In cool weather (below 20 °C (68 °F)) noticeable heat stress was not a problem through 4 consecutive turnarounds.

Finally, Whinnery (4)--observing ground crew under simulated chemical warfare conditions--noted significant thermal stress including symptoms of heat exhaustion, cramps, syncope, and cardiac arrhythmias. Recovery from heat stress was not easily achieved in a 12- to 16-h rest period. He also noted that many of the individuals treated for heat-related problems on a given day were prone to repeat episodes on following days, and these repeat episodes were often more severe than the first.

Because of the severe negative impact that the ground crew CDE has on job performance, several methods for reducing the thermal burden have been tried: (1) changes in the proportional times of work and rest cycles, (2) microenvironment conditioning, and (3) mechanization or "workarounds" of the task.

A concept has recently been proposed for modification of the CDE, separating the outer liquid-protective layer from the inner charcoal vapor-protective layer. During a combined liquid and vapor threat--which is expected to exist for only a short period--the wearer could be fully protected with the outer hood on and the chest area of the outer garment fully secured. During vapor hazard conditions that followed and persisted for an extended period, the wearer could doff the over-mask covering and unzip the outer garment jacket to

the waist, thus decreasing the insulative quality of the ensemble and hope-fully reducing the thermal burden to the individual. This unzipped configuration is termed "open bilayer."

The purpose of this laboratory investigation was to compare the thermal stress profile of the proposed open bilayer ensemble, configured to impart the lowest thermal burden, to that of the presently employed CDE. This limited laboratory investigation sought only to evaluate a conceptual, prototype bi-layer chemical protective ensemble configured to impart the least thermal en-cumbrance. Several critical factors will determine whether or not the ther-mal profile generated by this ensemble will be better than that of the present CDE at the time of actual deployment. These factors include: (1) materia used in the final construction of the ensemble; (2) chemical threat profile at the time of deployment--since this will dictate whether the suit is worn open or closed; (3) weather conditions; (4) work requirements; and (5) the physical work capacity ($\dot{V}_{O_2 \text{ max}}$) of the individual ground crew member.

EQUIPMENT AND PROCEDURES

Equipment

Current Chemical Defense Ensemble

The current CDE was donned in the prescribed manner: the subject wore cotton/polyester briefs and T-shirt, fatigue pants and jacket, and the CDE which was secured at ankles, waist, and wrists. The CDE jacket was zipped to the neck and the M17A1 mask with M6A2 butyl hood was put on and fastened down (Fig. 1). The average weight of the ensemble was 7.7 kg (16.9 lb).

Bilayer Chemical Defense Ensemble

The prototype open bilayer ensemble was assembled from available component parts of existing ensembles. The von Blücher material undergarment was worn over cotton/polyester briefs and T-shirt. This inner layer fit much like cold weather long Johns, conforming closely to the body surface. The outer layer consisted of the current CDE jacket and pants with the foam charcoal liner re-moved. The M17A1 mask was worn over a Balaclava head covering also made of the von Blücher material. The butyl hood (M6A2) was not worn as part of the mask. The pants were worn secured at the waist and ankles. The jacket was secured at the waist although it was unzipped to the waist and allowed to lie freely open at the chest (Fig. 2). The average weight of this prototype en-semble was 5.9 kg (13.1 lb).

The subjects were permitted to wear their own comfortable walking shoes which were covered by the current chemical defense overboots. The M-17A1 protective masks were modified by removing the inner filter layer. During extended work the filters become saturated with water condensation and sweat, leading to increased inspiratory resistance; this increased resistance becomes a confounding effect. Chemical defense gloves (14 mil) were worn over cotton inserts with both ensembles.



Figure 1. Current ground crew chemical defense ensemble.



Figure 2. Prototype bilayer ground crew chemical defense ensemble.

Procedures

Experimental Protocol

Four healthy male volunteer subjects were obtained from the existing thermal subject pool at the USAF School of Aerospace Medicine, Brooks Air Force Base, Texas. Some relevant physical characteristics of the subjects are described in Table 1. The participants were briefed on the objectives and nature of the experiment and each gave his voluntary, informed written consent to participate in this study.

TABLE 1. PHYSICAL CHARACTERISTICS OF SUBJECTS

Subject	Sex	Age (y)	Height		Weight	
			cm	(in.)	kg	(lb)
1	M	40	173	68.1	80.7	177.5
2	M	39	173	68.1	68.4	146.1
3	M	41	173	68.1	80.2	176.4
4	M	32	178	70.0	72.0	158.4
Mean:		38	174.3	68.6	74.8	164.6

Subjects reported to the laboratory on the morning of the scheduled test and were weighed nude and instrumented. They donned the designated ensemble and were weighed again fully clothed. Instrumentation consisted of: a CM₅-configured ECG lead connected to a Hewlett Packard telemetry system for monitoring heart rate (HR); rectal thermistor inserted 10 cm (4 in.) for monitoring core temperature (T_{re}), and 6 skin thermistors located on the chest (T_{ch}), mid-thigh (T_{th}), lateral calf (T_{ca}), upper back (T_{ba}), upper arm (T_{ar}) and head (T_{he}). Mean skin temperature (T_{sk}) was calculated following Remanathan's method (3). Temperature and heart rate data were collected on a Digital Equipment Corporation model 11/23 computer.

Following the final dressed weigh-in, the subject moved to a place immediately outside the chamber (21 °C (69.8 °F)) and sat quietly for 15 min. After this baseline period, the subject entered the chamber where the following conditions existed: dry-bulb temperature (T_{db}) 27 °C (80.6 °F), wet-bulb temperature (T_{wb}) 19 °C (66.2 °F), and air movement approximately 2 m s⁻¹. The subject stepped onto a Quinton research treadmill and began to walk at a speed of 5.3 km h⁻¹ (3.3 mph) and 2% grade, approximating an energy expenditure of 350 kcal h⁻¹.

The protocol specified that the subject complete 4 consecutive cycles of 30-min work and 10-min rest periods. Following the final work cycle, the

subject remained fully dressed and rested within the chamber for 30 min while his recovery profile was monitored (Fig. 3).

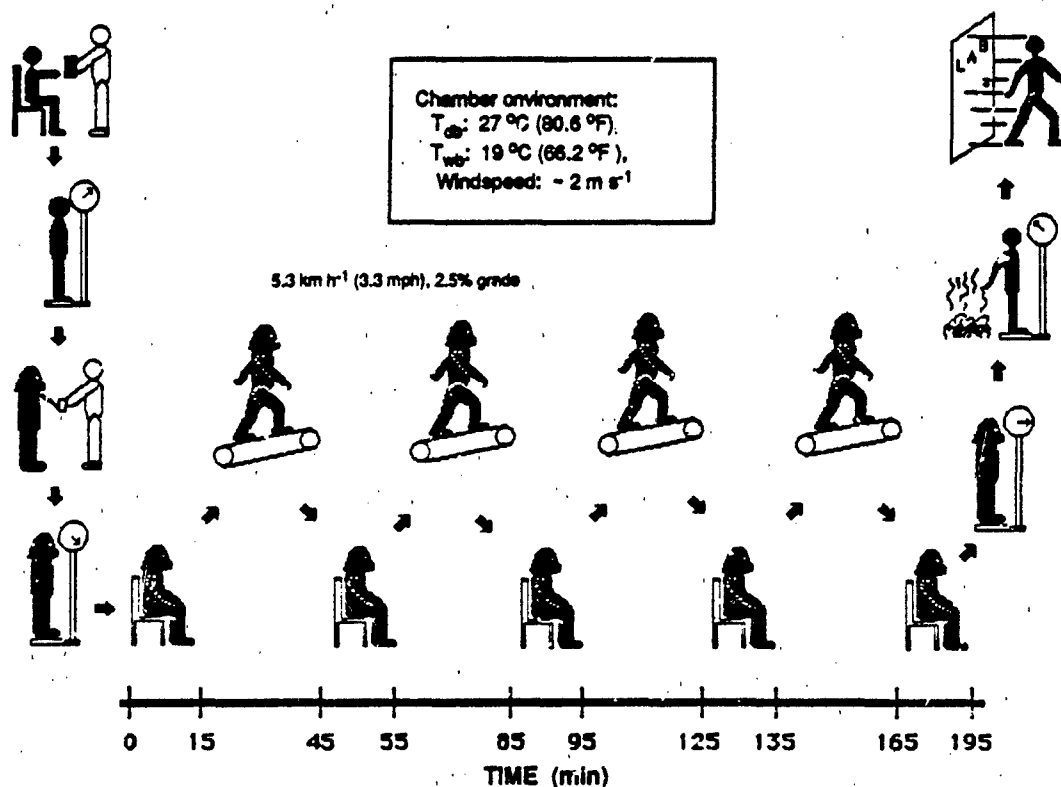


Figure 3. Outline of experimental protocol.

The subjects understood that the work requirement would be terminated for any of the following reasons: the subject's desire to stop (they were briefed on heat-stress symptoms); the medical monitor or inside observer requested the session to be terminated; or predetermined physiological endpoints were reached ($T_{re} > 39.0$ °C (102.2 °F) and/or HR > 180 beats min⁻¹). Immediately following the experimental session, the subject repeated the fully clothed and nude weigh-ins. Total sweat loss (SLT), sweat rate (SR), sweat evaporated (EVAP), and percentage of SLT that evaporated (% EVAP) were calculated using the pre- and post-session weights.

Both experimental conditions (CDE and open bilayer) were experienced by all subjects. A minimum rest of 1 day was given between repeat exposures. A randomized counterbalanced design was used to assign the order for each subject to don a given ensemble, thus reducing the possible bias due to learning.

Data Analysis

A repeated measures three-way mixed-model analysis of variance was employed in the analysis of the heart rate and temperature data. Standard

covariance techniques were used to estimate missing data. If global analysis indicated significance, paired t-tests were employed to determine where, within the given segmental analysis, differences occurred. The probability level for all tests was set at .05.

Paired t-test analysis was performed on the thermal sweat rate and evaporation data. The .05 probability level was also selected for these comparisons.

RESULTS

Figure 4 illustrates a single subject's dependent variable responses during the 2 experimental conditions. Unit analysis of a protocol as complex as this would not provide the clearest understanding of how a given ensemble performed during a distinct phase of the task. Therefore, the 3 distinctly different segments of the present protocol (work, rest, and recovery) were analyzed--and are reported here--separately.

Work Cycles

Core (Rectal) Temperatures

Mean core temperatures (T_{re}) for both ensembles during work periods are presented in Figure 5. The rectal temperature did not differ between the ensembles prior to work and remained statistically similar through the first 2 work intervals. From this point to the end of the experimental session, T_{re} remained significantly lower in the open bilayer ensemble than in the current closed ensemble. This session represented a 1.05 °C (1.9 °F) difference in T_{re} by the end of the fourth work cycle (Fig. 5).

Two subjects were unable to complete the fourth workout while wearing the current closed ensemble. Subject 1 did not attempt the fourth work interval due to a muscle cramp in the lower leg. The T_{re} at that time was 38.8 °C (101.8 °F) and rising. It was unlikely that he would have completed the final interval before attaining the maximum allowable temperature. Subject 3 was stopped after reaching a T_{re} of 39.0 °C (102.2 °F) at a point 25 min into the final work interval.

Subject 1 was also unable to complete the fourth workout while wearing the open bilayer ensemble. A lower back spasm forced him to quit 15 min into that work interval. The T_{re} at the time of this request to stop was 37.8 °C (100 °F) and stable. He most likely would have completed the work task had he not been forced to stop.

The T_{re} data suggests that under the present experimental conditions, body heat storage is more rapid for a ground crew member wearing the closed, current CDE than for one wearing the bilayer ensemble, and that--even for these rather moderate conditions--the time on task would be limited.

Skin Temperatures

Mean skin temperature for each work interval is also shown in Figure 5. Initial skin temperatures were statistically similar; however, significant

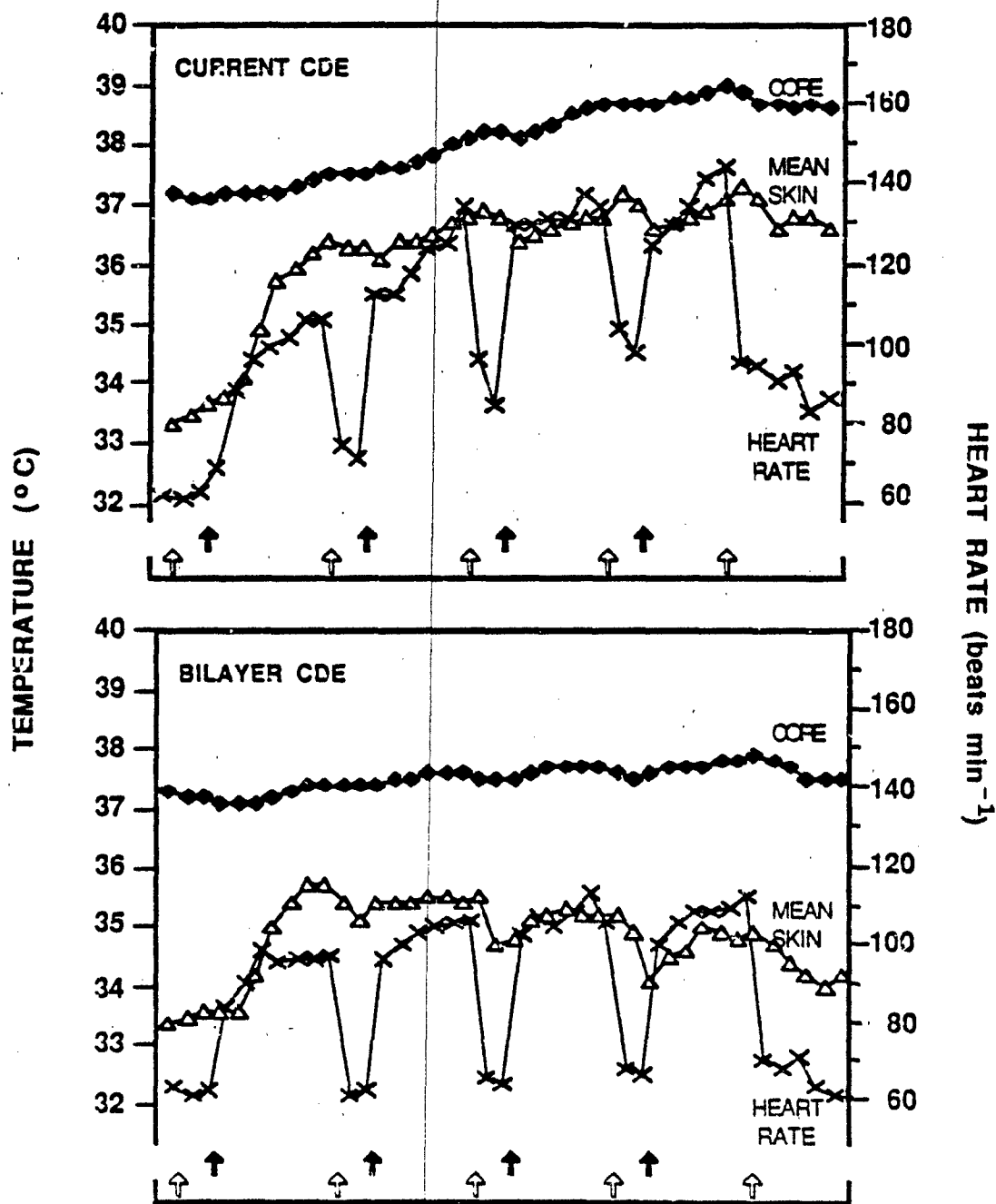


Figure 4. Physiological profile for one subject's performances under both experimental conditions (CDE and open bilayer ensembles). Arrows indicate initiation of rest (open) or work (closed).

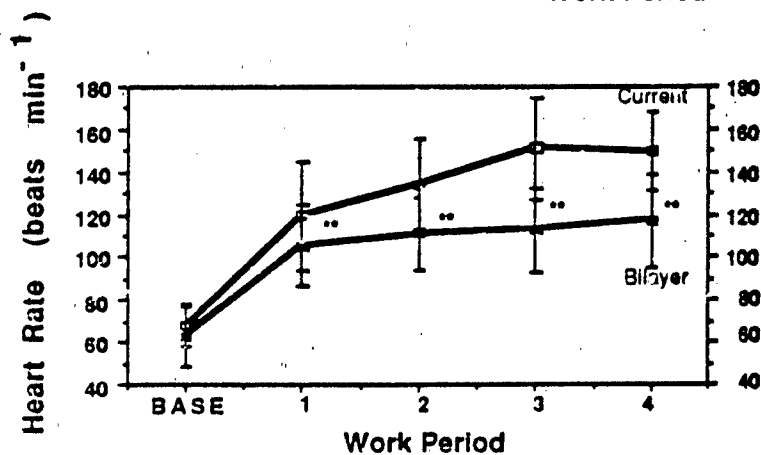
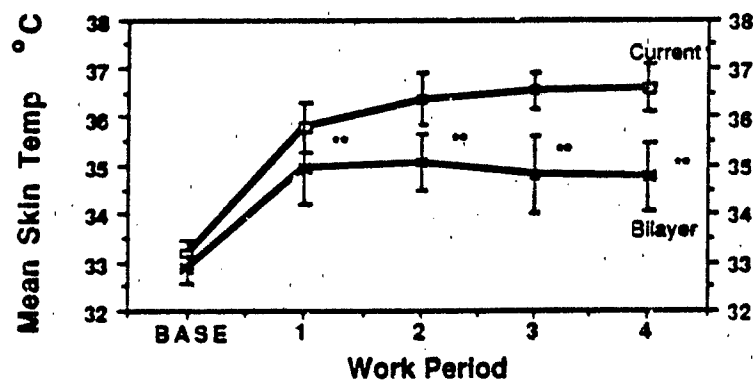
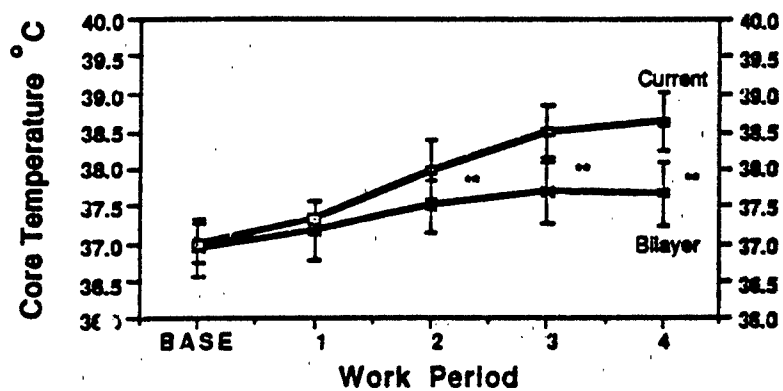


Figure 3. Mean (\pm S.D.) temperatures and heart rates during work periods for N = 4 subjects. Statistical significance ($p < .05$) indicated by double asterisks.

differences between ensembles were identified for all intervals of work. A maximum difference between ensembles of 2°C (3.6°F) was observed during the final workout.

Significant ensemble-by-work-interval differences were noted in some of the individual skin temperatures as well. Differences in chest (T_{ch}) and arm (T_{ar}) temperatures were highly significant. Beginning with similar values, these temperatures became increasingly different with successive work stress--demonstrating their largest difference during the fourth work interval.

Head temperature (T_{hd}) demonstrated that no thermal advantage was gained by removing the M6A2 hood from the mask and replacing it with the von Blücher Balaclava. A significant difference occurred only during the final work interval, and at this advanced point the influence of this body regional difference on core temperature would appear to be minimal.

Heart Rates

Figure 5 also shows the mean HR for each of the work intervals. Ensemble-by-interval differences in mean HR were not significant at baseline (4 beats min^{-1}) but became significant during the first interval ($14 \text{ beats min}^{-1}$), peaked during the third interval ($37 \text{ beats min}^{-1}$), and remained at this peak level for the final work interval.

The results of the work segment imply that although the absolute work requirement did not change over time, the ability of the ground crew member to perform a specific task was compromised more while wearing the current closed ensemble than while wearing the open bilayer ensemble.

Rest Cycles

The mean T_{re} , T_{sk} , and HR during rest cycles are given in Figure 6. The mean values observed while wearing the bilayer ensemble were lower than those observed for the current ensemble, and the differences between the 2 ensembles increased with time. The rest intervals were clearly insufficient to achieve a significant recovery between workouts. At best, the rest periods momentarily delayed the increase in a given variable. This plateauing is most likely due to a temporary reduction in generated heat resulting from a reduction in work.

Post-Work Recovery

The recovery period following the last work interval--shown in Figure 7--began with elevated values carried over from the work segment. The value for a given variable of interest was significantly higher throughout the recovery period for subjects wearing the closed current CDE than for those wearing the open bilayer assembly. The rate of decrease in a given variable was roughly the same for both ensembles during the 30-min recovery period. Neither ensemble allowed a given variable to return to baseline by the end of the recovery period (Fig. 7). The implication from these results is that personnel in the open bilayered CDE would probably return to baseline sooner than personnel wearing the closed current CDE, primarily because they begin the recovery period at a lower temperature and HR. There is no evidence from these data that the bilayered CDE expedites the heat dissipation during recovery.

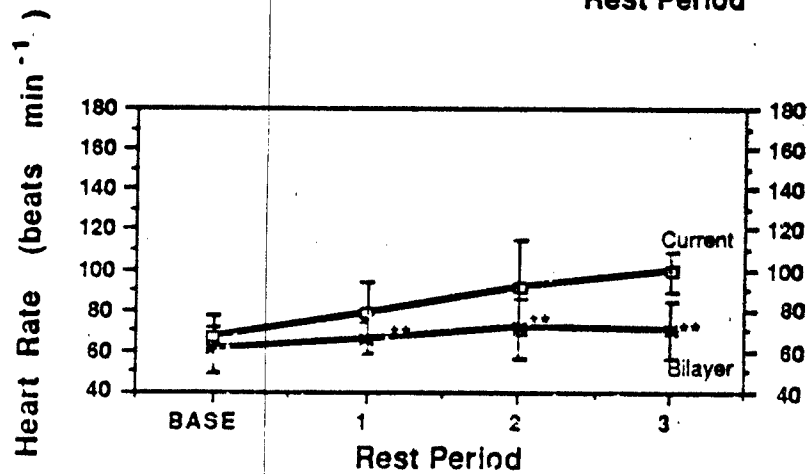
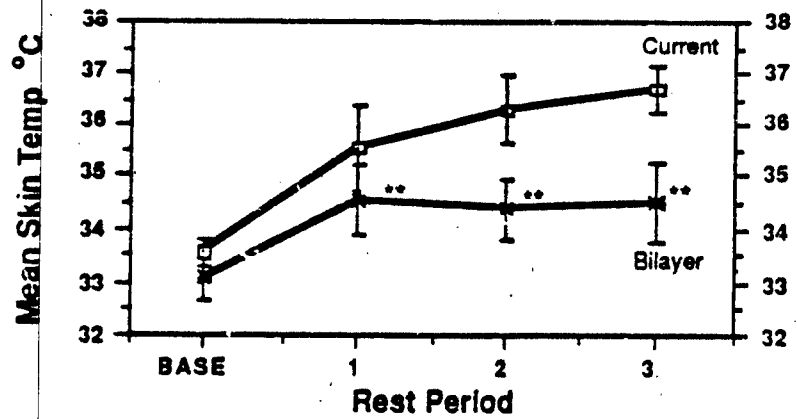
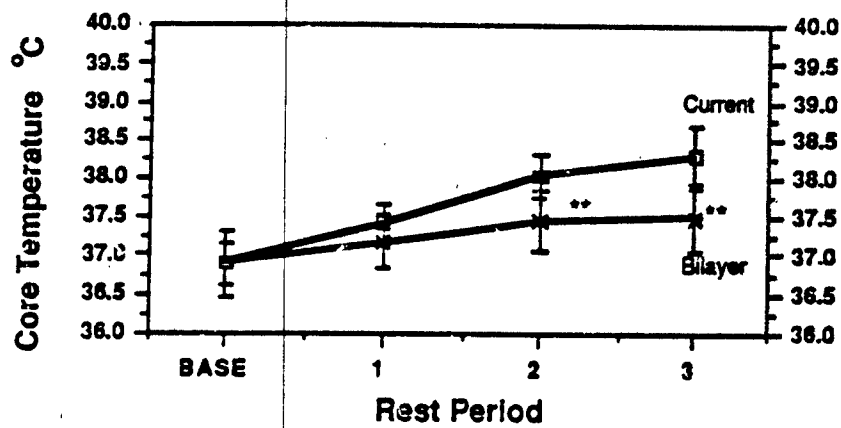


Figure 6. Mean (\pm S.D.) temperatures and heart rates during rest cycles for N = 4 subjects. Statistical significance ($p < .05$) indicated by double asterisks.

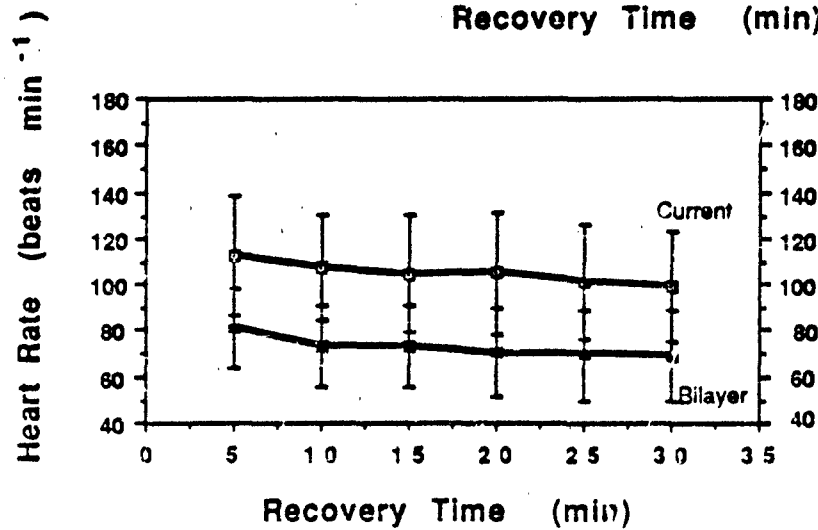
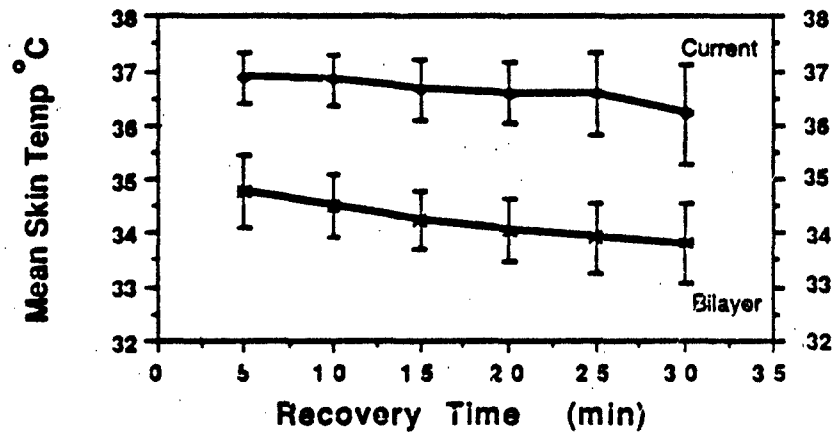
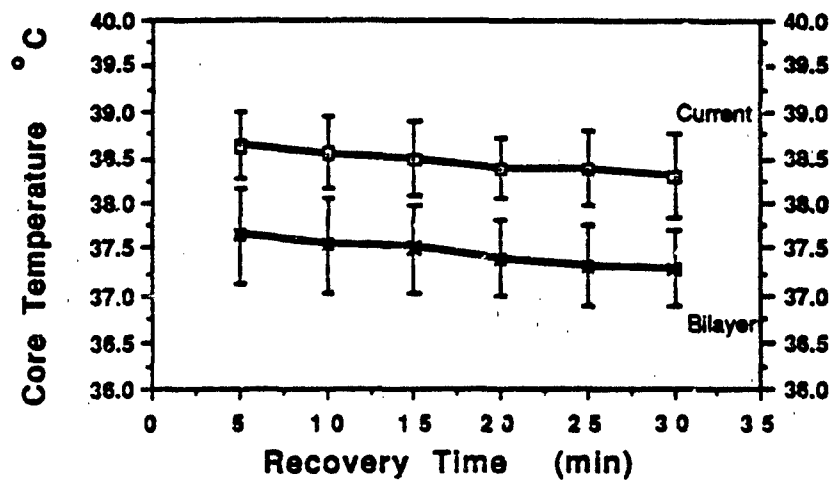


Figure 7. Mean (\pm S.D.) temperatures and heart rates during recovery after completion of final work period for N = 4 subjects.

Thermal Sweating

Group mean values and paired t-scores for the thermal sweat parameters are given in Table 2. Total sweat production was significantly less while wearing the bilayer ensemble compared to the current ensemble and, although the evaporation rates were slightly more in the current CDE, the bilayer assembly allowed a significantly greater percentage of the total sweat to evaporate. This finding indicates that individuals wearing the current CDE secrete a far greater amount of sweat, but that much of it penetrates through and evaporates from the outer surface of the ensemble. The body receives little cooling effect from this remote surface evaporation. In contrast, the open bilayer ensemble is associated with lower sweat production and a greater percentage of evaporation. Presumably, this enhanced heat dissipating effect is due to better air circulation close to the surface of the body which allows for better evaporation, thus better heat dissipation. The comparative sweat production and evaporation data are summarized in Figure 8.

TABLE 2. MEAN (\pm SD) SWEAT AND EVAPORATION VALUES

Ensemble	Sweat lost (liters)	Sweat rate (liters h ⁻¹)	Evaporation (liters)	Percent evap. ^a
CDE	2.50 (0.84)	0.90 (0.28)	0.35 (0.17)	39.0 (11.3)
Bilayer	1.38 (0.31)	0.47 (0.08)	0.30 (0.04)	65.7 (11.1)
t-value	3.287 ^b	3.871 ^b	0.638	-4.42 ^b

^a Percent nude body weight lost by evaporation

^b $p < .05$

DISCUSSION

Thermal stress resulting from moderate work while wearing the current CDE has compelled the research community to identify means to reduce this burden and by doing so, to increase the ground crew work tolerance times. The purpose of this limited evaluation was to compare the thermal stress profile of an open bilayer ensemble to that produced by the currently employed closed CDE.

The results clearly demonstrate that even under mild environmental conditions ($T_{db} = 27^{\circ}\text{C}$ (80.6°F), $T_{wb} = 19^{\circ}\text{C}$ (66.2°F)) and light-to-moderate work requirements (1.2 L min^{-1}), the current CDE imposes a work-limiting thermal burden. These results concur with those reported for other ground crew personnel (2, 4), although they are less dramatic.

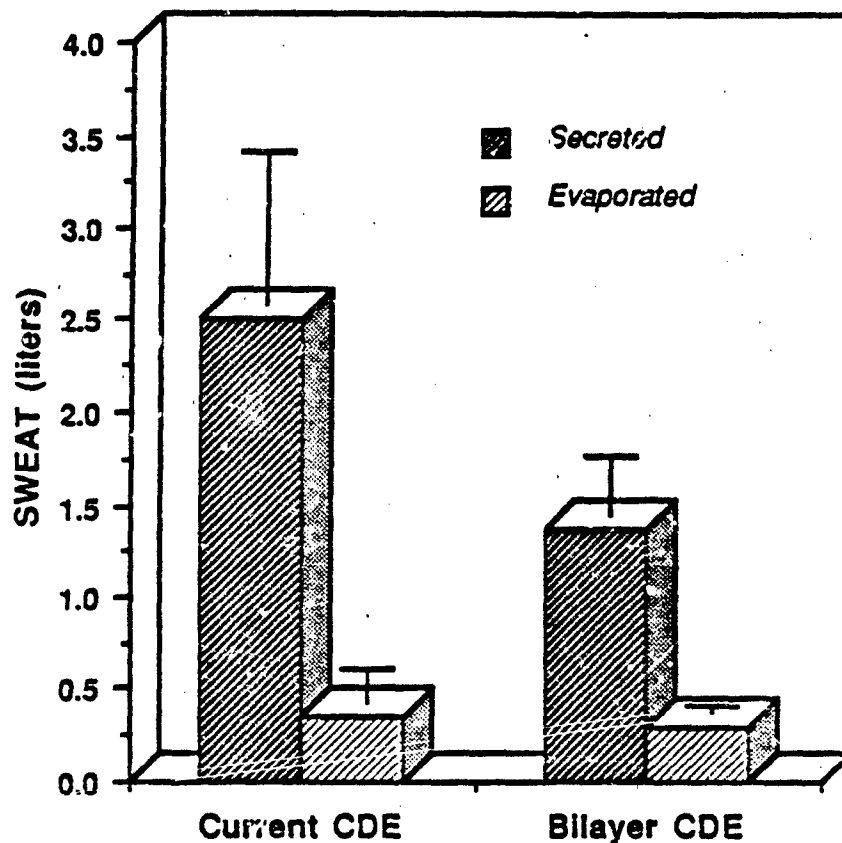


Figure 8. Mean (\pm S.D.) sweat production and percentage evaporation during experiments (N = 4 subjects).

Apparently, the prototype bilayer CDE worn open allows better heat dissipation through evaporation of sweat than does the current CDE worn closed. This ensemble has the double advantage of reducing heat storage and limiting dehydration.

The results of this limited laboratory comparison must be kept in perspective. Changes in any of the parameters defining the limits of this study would likely diminish the apparent advantage noted by the wearing of the prototype ensemble.

CONCLUSIONS

Wearing the prototype open bilayer ensemble--with the liquid-protective layer unzipped to the waist--resulted in less body heat storage and less associated cardiovascular demand than did wearing of the current ensemble closed. Total sweat secretion was significantly lower, and the percentage of that amount contributing to heat dissipation was significantly greater, while wearing the bilayer ensemble compared with the CDE.

The concept of a bilayer chemical defense ensemble, which would permit the ground crew member to unzip the outer liquid-protective layer during a vapor-only threat scenario, has merit. Several key parameters (environmental conditions, persistent agent threat, work requirement, and maximum work capacity of the crew member) at the time of actual deployment would determine whether or not this ensemble would be any better, thermally, than the current chemical defense ensemble.

The success of the bilayer concept will depend upon the refinement of material design and the understanding of the limitations of its use.

REFERENCES

1. Myhre, L. G. Field study observations of physiological responses of USAF groundcrew performing rapid runway repair activities. Aerospace Medical Association Scientific Meeting, Bal Harbour, FL, 10-13 May 1982. Aerospace Medical Association Preprints, pp. 45-46.
2. Myhre, L. G. Conversation concerning research on the metabolic cost of performing rapid runway repair by USAF ground crew in chemical defense clothing, Research Physiologist, Chemical Defense Branch, School of Aerospace Medicine, Brooks Air Force Base, Tex.
3. Ramanathan, N. L. A new weighting system for mean surface temperature of the human body. J Appl Physiol 19:531-533 (1964).
4. Whinnery, J. E. Conversation concerning aeromedical aspects of wearing chemical defense personal equipment in hot weather, Clinic Commander, Kelly AFB, TX, Nov 1986.
5. Yousef, M. K., C. T. Rasmussen, and L. G. Myhre. Physiological stresses associated with U.S. Air Force groundcrew activities. USAFSAM-TR-85-61, May 1988.